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"Diesel Vehicle Conversion Technology for Natural Gas Dual Fuel"

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ABTRACT

With the increasing concern regarding diesel vehicle emissions and the rising cost of diesel fuel, more medium and heavy-duty diesel vehicle fleets internationally are pursuing the option of conversion to natural gas (liquid or gaseous). Dual fuel conversion technology provides the opportunity to retain the desirable characteristics of the diesel engine, yet significantly reduce emissions and fuel cost. With the "generic" type of dual fuel conversion systems provided by Electronic Fuel Control (EFC), vehicles currently in service with direct injected engines can be retrofitted without engine modifications. The EFC generic type of dual fuel conversion system can be employed across many diesel vehicle types in a fleet. The generic system is a computer controlled, closed loop system having pre-programmed engine OEM power and torque curves contained in a read only memory (PROM) chip in the controller. The EFC dual fuel system constantly adjusts the ratio and flow of natural gas and diesel fuel according to vehicle load and speed, thereby operating efficiently throughout the entire load curve. Diesel fuel is used as the pilot for ignition of natural gas. A ratio of 85% natural gas and15% diesel is the targeted fuel balance. Emissions tests performed by an EPA laboratory for Navy school bus conversions indicate a 48% reduction in NOx and 24% reduction in CO_2. There was also a 90% reduction of smoke during snap idle exhaust opacity testing. A vehicle can be retrofitted in one day, and depending on the fuel storage capacity, at a cost between $12,000 - $15,000 by the local distributor/ installer.

INTRODUCTION

Diesel engine vehicles have been the workhorses of most nations. Their power, torque, and long life are ideal for mass transportation, heavy hauling, and numerous work applications. With these attributes also come higher than desired carbon dioxide greenhouse gas, nitrous oxides, and particulate matter emissions. For countries who have decided to reduce diesel engine emissions and/or reduce diesel fuel consumption, the use of natural gas fuel, coupled with significantly reduced diesel consumption, provides the opportunity to retain diesel vehicle attributes while reducing emissions and diesel fuel consumption.

Engines operating on a combination of natural gas (compressed natural gas or liquefied natural gas) and diesel fuel simultaneously are called dual fuel. The majority of blended fuel is natural gas-75% to 85%, with diesel fuel acting as the pilot for natural gas ignition. This combination of fuels allows the engine to maintain the diesel compression ratio, along with its economy, while providing the substitution of diesel fuel with less expensive, cleaner burning natural gas. No engine modifications must be made.

A number of approaches and technologies, from engine modifications to hardware additions, have been tried in order to allow diesel engines to utilize natural gas, resulting in varying degrees of success. Much R & D continues today in these areas. Cost, time, performance, fuel ratio, maintenance, and emissions reductions are all important considerations in deciding which dual fuel approach is optimum for each purchase decision. The ease of adapting a generic dual fuel conversion system to various diesel engine types is an important consideration for fleet managers.

A very successful approach to utilizing dual fuel is to retrofit existing vehicles with the EFC generic electronic closed loop conversion systems. With this type of system, the vehicle follows the original engine manufacturer's power and torque curves and requires no engine modification. It takes approximately 1/2 day for one technician and one engineer to convert a public transit bus. A targeted blend of 85% natural gas and 15% diesel fuel is reported in high load/high RPM conditions. Users indicate less wear on engine parts with reduced maintenance and oil changes. Emission testing indicates NOx reductions of 48%. CO2 greenhouse gas is reduced by at least 24% (as compared to 12% with a dedicated CNG engine). Visible "smoke" is virtually eliminated after startup. Dual fuel conversion systems installed on medium to heavy-duty vehicles range from $12,000 - $15,000.

DIESEL VEHICLE NATURAL GAS DUAL FUEL CONVERSION SYSTEMS

Dual fuel conversion systems cannot be applied to pre-combustion engines. The first generation dual fuel conversion system is open loop with no computer control. Natural gas is released into the air intake before the turbo, utilizing the turbo boost to introduce the natural gas into the air stream. A set amount of natural gas is introduced to the system, which is totally independent of vehicle speed or load. These earlier systems have had problems with knocking and significantly increased overall fuel consumption.

There are currently three electronic dual fuel conversion systems. One system is engine specific and injects natural gas into a manifold at the intake valve where the gas mixes with air. The second type of electronic system, which is also engine specific, injects natural gas directly into the cylinders. The final type of electronic system, which is closed loop, is referred to as a generic system since it is not engine specific. This is the system produced by EFC. The whole process follows the pre-programmed power curve and torque curve of the engine, as designed by the original engine manufacturer,

GENERIC DUAL FUEL SYSTEM

The generic system is operated by a central computer controller, which makes it an electronically closed loop system. When the hardware is installed and calibrated, the vehicle retains the desirable characteristics of efficiency and dependability normally associated with the diesel engine cycle. This is accomplished by retaining the high compression ratio of the diesel cycle and using the compression ignition of diesel fuel as a pilot ignition for the natural gas. Through electronic control of natural gas and diesel fuel, the horsepower of the combined fuels matches that of the diesel alone without any temperature increase in the cooling or exhaust systems.

While operating in the dual fuel mode, natural gas is supplied to the engine air inlet manifold through electronic natural gas injectors. Diesel fuel is reduced to a minimum by controlling the fuel shut off lever (the governor rack) on the diesel injection pump. Various sensors provide feedback to the central controller regarding engine load, speed, exhaust temperature, and gas and diesel use. The controller automatically adjusts the fuel supply and ratio based on a built in algorithm on engine performance to meet the changing speed and load conditions of the vehicle. A ratio of 85% natural gas and 15% diesel is the targeted blend ratio. The engine can be switched from dual fuel operation to 100% diesel fuel operation in the event that the compressed natural gas supply is depleted. No internal modifications are required to the basic four-cycle diesel engine.

EFC GENERIC CONVERSION SYSTEM HARDWARE

The main items in the conversion system are a central computer controller, natural gas injectors, gas manifold, gas mixer, pressure regulator, gas lockoff solenoids, throttle position sensor, magnetic pickup, exhaust gas temperature thermocouple, diesel pilot actuator, a wiring harness, and dashboard fuel switch.

The central computer controller is the functional brain of the conversion system. It receives electronic signals from the throttle position sensor, magnetic pickup, thermocouple, and relays through the wiring harness. The controller interacts with the motor drive unit to diminish the supply of diesel fuel while introducing natural gas through a series of gas injectors at levels controlled by speed and load.

The entire process follows the pre-programmed power curve and torque curve of the engine, as designed by the engine original equipment manufacturer. The information is contained in a programmable read only memory (PROM) chip in the controller. This feature makes the EFC generic dual fuel conversion system stand-alone from other dual fuel conversion packages presently on the market. The EFC system constantly adjusts the ratio and flow of natural gas and diesel according to the vehicle load and speed, thereby operating more efficiently throughout the entire load curve. This mode of operation also results in improved emissions reductions over the entire load curve. The central computer control unit is patented.

Safety features are also built into the controller that will return the system to 100% diesel fuel operation if exhaust gas temperatures exceed recommended levels. This eliminates the unlikely possibility of engine damage caused by natural gas fuel.

Additional hardware includes a pressure regulator to reduce the compressed natural gas storage tank pressure of 200-240 bar (3,000-3,600 psi) to a pressure dictated by the engine program. (If liquefied natural gas is used, the regulator also reduces the subsequent gas pressure upon gasification.) There is a patent protected mixing device to properly homogenize the natural gas and air mixture as it is introduced into the air intake. Three specifically designed natural gas injectors are mounted on a gas manifold that delivers the required quantities of natural gas to the mixer. High and low pressure gas lockoff solenoids are used as safety devices. A magnetic pick up device is mounted in close proximity to the engine ring gear, which provides special voltage signals. An exhaust gas thermocouple is positioned in the engine exhaust pipe. A diesel pilot actuator is installed to a position where the fuel pump shut off lever (or the governor rack) can be adjusted to provide the optimum minimum amount of diesel fuel. If a manual dashboard fuel switch is installed, it allows the driver to select dual fuel operation or diesel only.

Additional Conversion Components Supplied by the Distributor/Installer

The additional components required to convert a vehicle to utilize natural gas are provided by the company who completes the entire conversion. These are typically "off the shelf" inventory items used in any vehicle to be converted, whether it has a diesel or a gasoline engine.

By far, the most costly items are compressed natural gas cylinders, also referred to as tanks. They can range in price from $300 - $1500 US depending on size and type. The number of tanks installed depends on the desired range before refueling, available space, and cost. The least expensive cylinders are made entirely of steel; they also weigh the most. Thin-walled steel or aluminum cylinders are available which are either partially or entirely wrapped in layers of polymers and epoxy or carbon fiber and epoxy. The most expensive cylinders are full carbon fiber composites offering a reduced weight advantage. No matter which cylinder type is selected, they must be mounted on special brackets that are then strategically installed in the vehicle.

If a liquefied natural gas fuel storage system is used in the conversion of a heavy-duty vehicle, this also has a high cost impact.

Each vehicle requires a fueling receptacle that allows either liquefied or compressed natural gas to enter the vehicle's fuel storage system. The connection for refueling will automatically shut off the natural gas flow when the storage system is full. Stainless steel tubing carries compressed natural gas throughout the vehicle's fuel system with connection points made with specific fittings for the application. For safety purposes, a main manual gas shutoff valve is also installed on the vehicle.

It is important to remember that only experienced, qualified installers should perform vehicle conversions.

FUNCTIONAL DESCRIPTION OF THE EFC GENERIC DUAL FUEL SYSTEM

The magnetic sensor is mounted in close proximity to the engine ring gear. Each time a gear tooth passes in front of the magnetic pick-up pole face, a voltage signal is developed. Since the frequency of the signal is proportional to engine speed, it is used in the controller to sense engine RPM. The measured engine RPM is compared to a foot pedal command which is supplied from the throttle position sensor. The foot pedal command is conditioned to function with the existing vehicle mechanical governor housed in the diesel fuel pump system. The conditioning function of the foot pedal is to match the characteristics of either a limiting speed, min-max type, or a variable speed mechanical governor. The conditioned foot pedal command is compared to the actual engine speed, and the signal is in turn supplied through a least detect circuit to the gas injectors.

The least detect circuit has three inputs supplied to it. The first is through the basic governing path as just described. The second input is from exhaust gas temperature, which is measured by a thermocouple probe in the engine exhaust stream. The purpose of the temperature limiting function is to override the amount of natural gas being supplied to the engine should the exhaust temperature exceed a preset limit. The third input into the least detect system is a map of engine RPM and gas delivery. The purpose of this function is to provide the same engine RPM versus torque output as achieved when operating in the pure diesel mode.

The diesel pilot fuel is controlled through the shut off lever (or the governor rack) of the fuel pump. With diesel fuel limited, the compressed natural gas injectors will supply the necessary compressed natural gas to provide the normal diesel engine horsepower. To provide diesel pilot limiting, engine speed is compared to pilot position. From this comparison the control electronics drive the diesel pilot actuator to a position where the fuel pump shut off lever (or governor rack) is adjusted to provide the optimum minimum diesel fuel. As engine speed changes, a new optimum position of the fuel pump shut off lever (or governor rack) will be established through the movement of the diesel pilot actuator as previously described.

The amount of compressed natural gas delivered to the engine is controlled by the central computer controller and will vary depending on speed and load. The computer proportionately meters the amount of natural gas through three pulse injectors while simultaneously controlling the amount of diesel cutback via a diesel pilot actuator. Maximum displacement of diesel with natural gas occurs when the demand for power is increased, which in turn minimizes the amount of undesirable emissions without sacrificing performance and efficiency.

Certain logic is required to supply the engine with natural gas. Six inputs are required to control the electronics prior to allowing the gas solenoids to be turned on which releases the flow of gas to the engine. The inputs are as follows: 1. engine running, 2. functional thermocouple, 3. battery power applied, 4. foot pedal sensor connected to the controller, 5. engine exhaust temperature > 200 C, 6. gas "on/off" switch and/or gas supply switch closed. If all the inputs are present, then four outputs are made available from the control electronics. First, the solenoids are turned on. The second is an output to illuminate the dashboard indicator light. The final two outputs are "okay's" given to adjust the diesel pilot fuel and operate the gas injectors.

STOP AND START DRIVING CYCLE

The EFC generic system restricts diesel fuel supplied to a "pilot" quantity. Only enough diesel is supplied to the engine to overcome its own internal friction and windage losses, and typical fixed operating loads such as alternator, lights, air conditioning and air compressor. An engine running on "pilot" has no power to accelerate or drive against a load. Developing engine power in excess of this "pilot" quantity requires the injection of natural gas. As the driver depresses the foot pedal, natural gas is injected in proportion to both throttle position and vehicle speed in order to develop power and acceleration. The generic system can also introduce gas at 5%-15% when the engine is idling. This dramatically reduces the smoke opacity and NOx emissions.

In normal city driving, the vehicle is frequently starting and stopping. This constant acceleration/deceleration condition creates maximum torque demand. Upon each acceleration, natural gas consumption peaks to 80% - 85%.

VEHICLE INFORMATION REQUIRED PRIOR TO CONVERSION

There are many different types of diesel vehicles, engines, and fuel pumps. It is absolutely imperative that specific information be provided by the vehicle owner to determine exactly which combination (mostly sizing related) of dual fuel conversion equipment is required to perform the conversion. Since the generic dual fuel conversion system is operated by a central computer controller, the information is also needed in order to properly program the unit so the vehicle will mimic the power, torque, performance, and efficiency of the diesel engine after conversion.

No information may be omitted in order to achieve the best possible results. For example, one cannot assume that a specific manufacturer's bus with the same rated horsepower, will have identical diesel fuel pumps. This is not the case as has been discovered in practice. In the conversion process, each fuel pump design is adapted with a specific method and hardware employed in order to cutback and fully control the flow of diesel fuel.

Currently, there are only two physical conditions that preclude a diesel vehicle from being converted with the EFC dual fuel system. Before any information is gathered about the vehicle, it must be confirmed that the vehicle has a direct injection engine (no premixing of diesel fuel). It must also be confirmed that the diesel fuel pump does not have governors that prohibit the control of diesel fuel. If the engine is direct injected and the governors can be controlled, then the following information must be supplied about each specific vehicle to be converted:

Vehicle:	manufacturer, model, year
Engine:	manufacturer, model/type, serial number, rated hp, liters
Injector pump:	manufacturer, model
Batteries:	number of batteries, voltage per battery
RPM:	low idle RPM, maximum RPM
Exhaust pipe:	outside diameter
Air intake hose/pipe:	outside diameter
Fly wheel tooth count:	exact number of teeth (which may visually have to be counted)
Copies of curves:	power, torque, fuel (obtained from engine manual)

CONCLUSION

EFC “generic type” dual fuel conversion technology, utilizing either compressed or liquefied natural gas, has proven diesel vehicles can be successfully and economically retrofitted to utilize natural gas dual fuel. No engine modifications are required and vehicles retain the diesel engine qualities of performance, torque, power, and efficiency. On-the-road results indicate diesel fuel consumption can be offset by as much as 85% with natural gas. Along with this comes the benefit of significantly reduced CO_2 greenhouse gas, "smoke", and NO_x emissions. Since the system is generic, it can be applied to various diesel engine vehicles in a fleet. Conversions can be performed in approximately 1/2 day by two skilled technicians/engineers at a cost of $12,000 - $15,000.

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